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A Social History of Disease: Contextualizing the Rise and Fall of Social Inequalities in Cause-Specific Mortality

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Abstract Fundamental cause theory posits that social inequalities in health arise because of unequal access to flexible resources, including knowledge, money, power, prestige, and beneficial social connections, which allow people to avoid risk factors and adopt protective factors relevant in a particular place. In this study, we posit that diseases should also be put into temporal context. We characterize diseases as transitioning through four stages at a given time: (1) *natural mortality*, characterized by no knowledge about risk factors, preventions, or treatments for a disease in a population; (2) *producing inequalities*, characterized by unequal diffusion of innovations; (3) *reducing inequalities*, characterized by increased access to health knowledge; and (4) *reduced mortality/disease elimination*, characterized by widely available prevention and effective treatment. For illustration, we pair an ideal-types analysis with mortality data to explore hypothesized incidence rates of diseases. Although social inequalities exist in incidence rates of many diseases, the cause, extent, and direction of inequalities change systematically in relation to human intervention. This article highlights opportunities for further development, specifically highlighting the role of stage duration in maintaining social inequalities in cause-specific mortality.

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Introduction

The structure of mortality has changed substantially: mortality occurs much later in life (Kirk 1996), and individuals now regularly expect to avoid causes of death that once frightened populations (Shah 2010). Concurrently, persistent and often increasing socioeconomic inequalities in mortality suggest that sociostructural factors play a powerful and growing role in shaping health (Link 2008; Marmot 2004; Meara et al. 2008; Pappas et al. 1993; Singh et al. 2002). Yet, researchers examining cause-specific mortality have been challenged to explain why inequalities in some causes appear to widen, dissipate, and even invert themselves over time (Krieger et al. 2012). Understanding social inequalities in health requires the development and deployment of theories that assist in elucidating why such changes are occurring—and specifically, why inequalities arise, persist, invert, and grow. Underlying these prominent facts about the association between social factors and all-cause mortality is an intricate constellation of findings about particular causes of death. This study contextualizes particular causes of death within a sociomedical context in order to understand how inequalities in cause-specific mortality may systematically change over time.

Demographic and Epidemiological Transitions

To understand how the causes of death have changed, we build on two existing conceptual frameworks focused on historical changes in population health: the demographic and the epidemiological transition literatures.

Demographic transition theory (DTT) conceptualizes four stages of temporally dynamic processes resulting from changes in mortality: (1) a pre-industrial stage in which birth and death rates are high and population size is relatively low; (2) a stage of rapidly declining death rates as social conditions improve and opportunities to prevent disease are discovered; (3) a stage of declining birth rates as the likelihood of offspring survival increases and it becomes possible to choose one's number of children; and (4) a stage in which birth and death rates are both low and the population level remains high by historical standards (Caldwell 1976; Chesnais 1986/1992; Kirk 1996).

Epidemiological transition theory (ETT) further contextualizes the historical change in mortality by focusing attention on the massive shift in the types of causes of death from infectious to chronic human-made diseases (Omran 1971). Specifically, the theory initially conceptualized three stages of death: (1) a stage of pestilence and famine in which mortality is variable and also high due to vulnerable populations and virulent infectious diseases, (2) a stage of receding pandemics in which both the mortality rate and the variability in that rate decline, and finally (3) a stage of degenerative and human-made diseases (Omran 1971). Further investigation has paved the way for an inequalities approach by noting, for instance, that regional factors influence progression through the epidemiological transition (Stevens et al. 2008).

Although both theories posit that the change in mortality has produced important shifts in the structure of society and the importance of death, neither has specifically examined how such shifts may have interacted with social inequalities. The following sections first situate this discussion within the context of the theory of fundamental social causes of health disparities and then detail four hypotheses about how inequalities might change in relation to the fundamental causes over time.

Fundamental Social Causes of Health

Fundamental cause theory (FCT) was developed to explain why the association between socioeconomic status (SES) and mortality has persisted across places and times and in the face of radical changes in the diseases and risk factors that are presumed to account for the association (Link and Phelan 1995; Phelan and Link 2013; Phelan et al. 2010). The theory was developed in the era of risk-factor epidemiology and within the context of an approach to health inequalities that claimed that the way to address such inequalities was to discover—as well as block the influence of—modifiable risk factors lying between SES and disease in a causal chain. Running counter to this seemingly persuasive formulation was historical evidence suggesting that even as prominent risk factors (e.g., a contaminated water supply) and disparity-related diseases (e.g., small pox) were eradicated, the association between SES and all-cause mortality reemerged because an entirely new set of risk-factor mechanisms came to the fore (e.g., smoking cessation, exercise, access to life-saving cancer screening) to influence a completely different set of diseases (e.g., heart disease, stroke, lung cancer). How could this occur? The proposed answer implicates SES-related resources of knowledge, money, power, prestige, and beneficial social connections as flexible resources that can be deployed in vastly different health circumstances to ensure better health outcomes for individuals and groups with advantageous circumstances.

In essence, FCT asserts that mechanisms are replaced as individuals, households, and social groups deploy unequally distributed SES-related resources to gain privileged access to protective factors and to help avoid risk factors. However, the profile of such factors is situational and must thus be placed in a particular place *and* a particular time, effectively tying the control of disease with the development of social inequalities. For example, regarding cholera in the nineteenth century, a person with greater resources was better able to avoid areas where the disease was rampant; and communities with more resources were better able to prohibit the entry of infected persons and secure better access to health services and cleaner water. Taking heart disease in the current era as another example, a person with greater resources is better educated, better informed, and better able to maintain a heart-healthy lifestyle, access the most efficacious preventions and treatment, and inhabit contexts that—or modify contexts to—improve population health and reduce cardiac disease.

Critical to the theory is whether and to what extent knowledge and technology in a particular setting allow control of the diseases that afflict human beings in that setting. To the extent that control of disease is possible, social inequalities in mortality arise because the capacity to effectively prevent mortality is unequally distributed, access is unequally gained, and benefits of newfound knowledge and technology are distributed

unequally throughout the population (Link 2008; Link and Phelan 1995; Link et al. 1998; Phelan and Link 2005, 2013; Phelan et al. 2004, 2010). Firmly situating part of these growing social inequalities in relation to the unequal diffusion of innovation, researchers have noted that inequalities in the incidence of human immunodeficiency virus (HIV) (Rubin et al. 2010), colorectal cancer (Saldana-Ruiz et al. 2013), and lung and pancreatic cancers (Rubin et al. 2014) have increased alongside increasing intervention in behaviors, policy, prevention, and treatment. Furthermore, Wang et al. (2012) linked the development of these inequalities to the propensity to diffuse information. Finally, Clouston et al. (2014) linked newly developed inequalities in suicide rates to the information diffusion, since the 1990s, of selective serotonin reuptake inhibitor (SSRI) antidepressants (a treatment for depression).

Since its first articulation, the theory has been qualified, elaborated, extended, and tested within the sociological literature (Link and Phelan 2010; Lutfey and Freese 2005; Miech et al. 2011) in ways that suggest the utility of further refinements. For example, the causal link from smoking to lung cancer was established nearly 50 years ago (Singh et al. 2002). This information was diffused through, and was more quickly adopted by, more advantaged populations, spurring unequal behavioral changes. Individuals with lower SES have been slower to change their smoking behavior (Huisman et al. 2005), giving rise to social inequalities in lung cancer mortality (Rubin et al. 2014). An example where differential access to diagnosis plays a key role is cervical cancer: although Pap tests have been available for 80 years, substantial and pervasive inequalities in testing rates persist (Link et al. 1998), resulting in socioeconomic inequalities in cervical cancer mortality that continue to widen (Parikh et al. 2003). Finally, the impact of introducing a new treatment is typified by the advent of highly active antiretroviral therapy (HAART) for acquired immune deficiency syndrome (AIDS) due to HIV. More advantaged populations tend to be better informed and able to access HAART, which has led to a rapid increase in racial and socioeconomic inequalities despite an overall reduction in HIV/AIDS–related mortality (Rubin et al. 2010).

In an elaboration and extension of the theory, Lutfey and Freese (2005) proposed that *fundamental causality* is a particular type of causation that can be abstracted from any particular instantiation (such as in health) and that as a type of causation, it is especially well suited to illuminating the significance of sociological factors in multiple content areas. In another extension, Freese and Lutfey (2011) explicated a greater range of structural factors, or multiple meta-mechanisms, which help explain how structural factors influence individuals. In addition to the prior emphasis on means, they proposed three additional meta-mechanisms—spillovers, habitus, and institutional processing—that help explain how contextual and individual factors might interact to impact health (see also Cockerham 1997, 2007). Healthy behaviors are an excellent example of such mechanisms because they are formed within status groups and depend heavily on social circumstances (Cockerham 2005). For example, although a person may not smoke, others in their contexts who do smoke nevertheless put the nonsmoker at risk of death from passive smoking (Öberg et al. 2011). Similarly, the sexual practices of some husbands put spouses at greater risk of contracting sexually transmitted infections, such as HIV (Clark 2004; Clark et al. 2006).

Although FCT has captured substantial attention in the broader sociological literature and has, through elaboration and extension, been connected to a broad range of sociological thought, there remains an underaddressed and conceptualized issue.

Seeking to understand the reproduction of SES gradients in different places and at different times, FCT needed to explain why the SES associations reemerged. As a result, the theory understandably focused on the production of new mechanisms (Chang and Lauderdale 2009; Link et al. 1998; Miech 2008; Rubin et al. 2010; Saldana-Ruiz et al. 2013; Wang et al. 2012) and the creation of new inequalities (Miech et al. 2011; Phelan and Link 2005). What this focus tends to underemphasize, however, is that as new mechanisms and new mortality inequalities are being produced, others should be in decline (Krieger et al. 2012). For example, Miech et al. (2011:920) noted that "the influence of widening disparities outweighs that of narrowing disparities" but did not explain why or when disparities narrow. Reducing disparities is the goal of research on inequalities and health, and a full accounting of social influences on health should be attentive to both the emergence and the decline of mechanisms linking social conditions to health outcomes.

Combining Theories

Three main concepts emerge from FCT, DTT, and EDT: (1) mortality has declined due to modification over time of the relevant mechanisms that lead to death; (2) the decline in mortality has major social, economic, and demographic impacts; and (3) social inequalities will change alongside reductions in mortality. Thus, we hypothesize that social inequalities in cause-specific mortality arise partly because social, economic, and structural factors influence mortality when diseases are preventable. Insofar as effectiveness of intervention narrows, we propose that social inequalities in cause-specific mortality rates will tend to follow a specific pattern of change over time, elucidated in Fig. 1. From this foundation, we argue that social inequalities in cause-specific mortality can be characterized as proceeding through four stages that imply different sociocultural processes linked to our ability to prevent disease.

Historical Stages

Natural Mortality

During the *natural* stage of mortality, the causes of death are not well understood, can cause substantial fears, and may be viewed as accidental, unfair, and at times malicious or even magical (Turner and Hanley 2010). For example, with regard to malaria, Shah (2010:43) characterized this period as one of deep-seated fears, stating that "diseases of hot climates frightened sixteenth century Europeans so much they thought that sudden exposure to heat could literally melt the fat inside a person." Furthermore, scientists, doctors, or other specialists may contend that a particular factor is the root cause of the particular cause of death, but those contentions have not (yet) been able to effectively reduce the risk of cause-specific mortality. For example, although apolipoprotein-ε4 is known to be a genetic cause of Alzheimer's disease, no treatments exist for Alzheimer's disease. Indeed, prior to the epidemiological transition, the majority of causes of death were unavoidable, rising and falling seemingly at random, even though many theories about their specific causes existed (e.g., miasmas). Therefore, social inequalities in

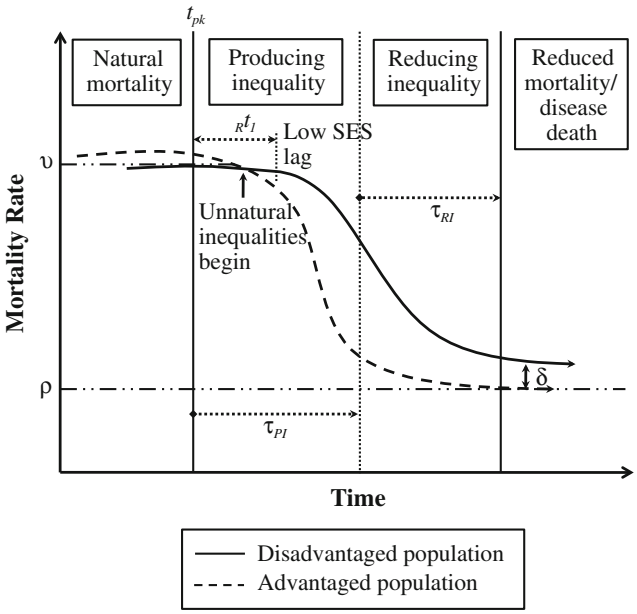

Fig. 1 Ideal characterization of the history of the risk of mortality for a single hypothetical cause of death as it is increasingly but unequally controlled

diseases in this natural stage may be variably and unreliably associated with diseases and may change over time. It is likely that diseases will sometimes favor advantaged groups, other times favor disadvantaged ones (as may be evident with autism (Liu et al. 2010)), and other times show no association with advantage.

Producing Inequalities

Upon the creation of knowledge, populations have a newfound capacity to reduce the mortality burden of a disease. FCT suggests that social inequalities arise in health during this stage; in particular, it directs attention to the importance of the preventability of disease or death in determining health disparities (Phelan and Link 2005; Phelan et al. 2004). When new information is diffused throughout a structured social space, some individuals will gain access to the new preventions and treatments because of their privileged access to resources (whether educational, political, social, or economic). As typified by FCT, this process is typically governed by a range of microprocesses operating around exposure, diagnosis, prevention, or treatment that synergistically create inequalities in health.

Reducing Inequalities

To the extent that health-beneficial innovations become more universally accessible and evenly distributed throughout the population, we might expect a decrease in social inequalities in mortality. This decrease occurs for two reasons. First, at some point, further reduction is impossible in the most advantaged populations because the innovation has saturated that group. Thus, inequalities between privileged and

disadvantaged groups will, at the very least, slow their growth. Second, if diffusion efforts are sufficiently focused and the innovation is made cheaper and more accessible, uptake among disadvantaged groups may grow. As a result, inequalities will stabilize and may even begin to shrink. For example, upon Salk's discovery of the poliomyelitis (polio) vaccine, people with greater resources were better able to access the vaccine; however, efforts to distribute the relatively inexpensive vaccine led to wide adoption, and inequalities fell quickly (Phelan et al. 2010).

Reduced Mortality and Disease Elimination

At a certain point, a specific health innovation may become universal, maximizing its impact on mortality for all groups. Thus, all at-risk populations approach an asymptote on their capacity to control disease: no more gains can be made, regardless of SES. This asymptote may be determined either by the effectiveness of the treatment or by the eradication of the disease itself. In the former case, which we term *reduced mortality*, a disease remains stable in its ability to cause mortality throughout a population. We term the latter case, in which the risk of death due to a disease reaches 0, as *disease elimination* (Dowdle 1998). In this special case, the disease no longer contributes to mortality, and it follows that social inequalities in this cause of mortality must have also completely disappeared. This is the most desirable outcome, although one of the hardest to achieve. Because of the theoretical simplicity (and lack of data), we restrict our discussion of disease elimination to this paragraph. Cholera provides a useful example of disease elimination in the developed world, but it also highlights how global inequalities may factor into the study of mortality trends. Snow (1849) showed that polluted water was related to cholera incidence. Efforts to clean drinking water have eliminated cholera as a cause of death in most of the developed world: cholera was first eradicated from England, and then France, followed by the rest of Europe. However, it remains a substantial killer in the developing world and has been particularly impactful in the 2010 Haiti earthquake. Other similar examples are plentiful: leprosy, the bubonic plague, malaria, and small pox all fill our historical record as important and devastating diseases that at one time killed many but are now eliminated from many countries and nearly eradicated. Nevertheless, many of these diseases are present in impoverished regions where the illnesses remain endemic and arguably nonpreventable (Durrheim and Speare 2003; Henderson 1976; Shah 2010; Stenseth et al. 2008).

Graphical Representation of Hypotheses

Figure 1 illustrates mortality rates for two socially unequal populations with respect to a specific disease outcome: those who are disadvantaged (solid line) or advantaged (dashed line). These hypothetical populations illustrate hypothetical trajectories across the four described disease stages. First, in Stage 1, both curves are at their pre-prevention levels (υ), and a SES gradient may be present, non-existent, or reversed, as has been represented here, using an oscillating line. This stage ends with the advancement of medical innovation (at time t_{pk}). After some period (τ_{PI}), mortality reductions in the disadvantaged group may equal or even outpace those in the advantaged group, potentially resulting in a reduction in δ. After some period of time

(τ_{RI}), the mortality rates meet a lower bound defined by the efficiency of the innovation (indicated by $\rho \geq 0$). The transitional period ends when further changes in social inequalities are limited and inequalities remain stable over time.

The following formalize the graphical hypotheses.

Hypothesis 1: Inequalities may exist prior to the advent of medical technologies, but these may be inverted and are likely to be stable with time.

Hypothesis 2: Lifesaving efforts will benefit those in the advantaged group first, resulting in the start of the second stage, which is characterized by an increase in social inequalities in mortality.

Hypothesis 3: Life-saving efforts will slow in their ability to ensure greater declines in mortality, and inequalities will begin to decay.

Hypothesis 4: After becoming broadly available, inequalities will be stable and may be small, but they will persist in the standard direction.

Data

We used disease-specific mortality counts at the county level in the United States to illustrate these hypotheses. Mortality counts are provided within age groups (10-year groupings limited to those aged 25 and older), by sex (male, female), and race (black, white), and are available for the years 1968–2009. The data were compiled from death certificates collected and made available by the National Center for Health Statistics (2012), which also supplied midyear population counts for each group. Data from 3,110 counties in the continental United States and Hawaii were used; we excluded counties whose borders changed during observation. We excluded data for persons under 25 years of age because mortality from most causes examined here is extremely rare in younger age groups. Finally, we excluded data from "other" races because the definition and the included populations have changed substantially during observation. These data have the benefit of being population-level data, thereby reducing sampling bias. To create a matching county-level index of SES, we adapted methods that make use of data from the 1970, 1980, 1990, and 2000 decennial censuses (Singh et al. 2002). We used principal components analysis to create a scale using five indicators: (1) proportion white-collar workers, (2) proportion with more than 12 years of education, (3) proportion with less than nine years of education, (4) proportion of households with access to a phone, and (5) proportion of families living above the poverty line. The data for intercensal years were linearly interpolated within counties. For interpretability, we standardized SES yearly so that each unit increase in SES represents 1 standard deviation in SES and so that the SES distribution is not biased to yearly changes in the importance of one specific measurement.

Case Selection

Analyses empirically illustrate the four hypothesized stages. In this study, we chose *a priori* four causes of death (multiple sclerosis, colorectal cancer, kidney infections, and thymoma) that we believed would ideally represent the full range of patterns. We made

this choice by using objectively attained preventability scores, ranging from not preventable (1) to very preventable (5) (Phelan et al. 2004). For each cause of death, preventability scores are provided, and mortality was measured using the International Classification of Disease (ICD) in use during the period of data collection (ICD-8 from 1968–1979; ICD-9 from 1980–1998; and ICD-10 from 1999–2009). For all cases, data from each period were highly comparable over these years.

Natural Inequalities: Multiple Sclerosis

Many diseases with unknown causes exist in the historical record; however, multiple sclerosis (MS) (ICD-10: G35) is a contemporary example of a disease in the natural inequalities stage. To date, little is definitively known about etiology, treatments are limited to managing symptoms, and there is no known cure (Miller et al. 2007). Moreover, although there is significant regional variation in MS incidence and mortality, the reasons for this pattern have yet to be elucidated (Beck et al. 2005; Rosati 2001). Thus, the significant variation and inequalities in the incidence of MS are "natural" or accidental, resulting from unknown exposures or unknown variation in cultural or health-related lifestyles whose effects on MS are unknown, rather than a product of intentional human modification.

Increasing Inequalities: Colorectal Cancer

Colorectal cancer—cancer of the colon, rectum, and anus (ICD-10: C18-21)—is the second leading cause of cancer mortality in the United States (Jemal et al. 2005), responsible for an estimated 49,920 deaths in the United States in 2009 (National Cancer Institute 2010). Mortality from colorectal cancer is preventable through the use of diagnostic colonoscopies and surgical techniques, including the removal of precancerous polyps and early-stage cancer (Hawk and Levin 2005). Colonoscopy was co-invented in 1969 by Dr. William Wolff (with Hiromi Shinya) who himself noted that it took more than a decade for many hospitals to start conducting colonoscopies (Wolff 1989). Since then, declines in mortality have resulted from both the uptake in colonoscopy procedures and declines in poor health behaviors, such as eating red meat and lack of physical inactivity (Edwards et al. 2010). Inequalities in colorectal cancer mortality are known to have risen partly because of misdistribution of information about, recommendations for, and risk factors for colorectal cancer (Saldana-Ruiz et al. 2013; Wang et al. 2012). Uptake of prevention and treatment has been subject to substantial social inequalities in screening, treatment, and ultimately mortality (Gorey et al. 2010, 2011; Saldana-Ruiz et al. 2013).

Decreasing Inequalities: Kidney Infections

To empirically illustrate the reduction in inequalities, we draw on mortality trends in kidney infections (ICD-10: N10-N12, N13.6, N15.1). Infections of the kidney are a highly treatable condition that currently kills a small number of individuals each year. The vast majority of cases are among sexually active and pregnant women, although men are also susceptible to infection. Phelan et al. (2004) characterized death from these infections as highly preventable. The infection is curable for 80 % to 90 % of all

cases with timely diagnosis and treatment (Abraham et al. 1941; BMJ 2010). Treatment has been common since antibiotics—effective, immediate, inexpensive, and easily used—were made available starting in 1941. As such, social inequalities may still arise through a number of micro-processes influencing diagnosis, treatment, and susceptibility.

Reduced Mortality: Thymoma

In the empirical analysis, thymoma (ICD-10: C37-38 (excluding C38.8) and D15.0, 15.1, and 15.2) was used to characterize the reduced mortality stage, although we could have chosen the less currently relevant cases of cholera or the Black Plague. Thymoma is very likely to be diagnosed because it is highly symptomatic, relatively slow-growing, and often benign. It has been treatable using surgical methods since the early 1900s (Mueller 2010), with high contemporary 5- and 10-year survival rates (Wright 2008). Because intervention was introduced in the early 1900s and is effective in all but the most invasive cancers, we expect few if any social inequalities in thymoma mortality.

Statistical Analysis

Graphical Analysis

To familiarize readers with each cause of death, yearly death rates were provided. Graphical analyses use age-, sex-, and race-adjusted mortality rates and are weighted to the U.S. standard population. Point estimates are presented along with nonlinear polynomial trend lines (calculated in Excel) on the aggregate data. For ease of understanding, graphical analyses present mortality rates for three equally sized SES groupings. To provide a concrete representation of absolute inequalities, we also provide yearly differences, calculated by taking the mortality rates for those living in higher-SES counties and subtracting the mortality rates for those living in low-SES counties, using bar graphs immediately below the yearly trends.

Multivariable Analyses

We modeled relative inequalities in mortality counts using negative binomial regression, which was used in lieu of Poisson regression because data are overdispersed ($\alpha > 0$), indicating that the variance is larger than the mean (Gardner et al. 1995). We control for age, race, sex, and urbanicity (the proportion of the population living in an urban area, defined as having more than 50,000 inhabitants). We used midyear population counts to model exposure. Mortality rate ratios (MRRs) were provided to aid in interpretation, and pseudo-R^2 was calculated to assess model fit.

Modeling Change Over Time

The hypotheses highlighted earlier mostly refer to how best to model yearly exposure to the risk of death in each situation. Year of death may be modeled differently depending on stage. In the case of natural and reduced mortality, or disease elimination, we expect that there may be change in the mortality rate over time due to unknown

causes, but this should not generally be relevant to SES inequalities. We modeled change over time in these models by including year of death as both a linear and a quadratic predictor. However, in models of reducing inequalities, mortality rates are likely to decline log-linearly as they approach a floor; we included the ln(Year of Death) to model this deceleration in decline. To examine associations between SES and mortality, we included SES and an SES × Year of Death interaction. SES alone shows a time-invariant effect of SES, and SES × Year of Death interactions models change in the impact of SES over time.

Characteristic Mortality Curves

Table 1 provides the average race-, sex-, and age-adjusted mortality rates per 100,00 population by year over the entire 1968–2009 period.

Figure 2, panel a (natural stage) shows yearly age-, race-, and sex-adjusted MS mortality rates for U.S. counties in the highest and lowest SES tertiles. The standard social inequalities in health are reversed (and the absolute difference is negative, as shown in panel b of the figure): those living in higher-SES counties are more likely to die from MS. Moreover, this gradient is largely stable over time, even as mortality rates change. Results support Hypothesis 1, showing an inverse relationship with MS mortality that is largely stable with time.

Multivariable results confirm this interpretation (Table 2, Model 1). Consistent with graphical analysis, we found that MS is positively associated with SES, creating a reverse gradient. Because the SES × Year interaction was not significant and did not improve model fit ($p = 0.108$), we do not present SES × Year interactions.

Figure 3, panel a, describes changes in colorectal cancer mortality rates in U.S. counties in the highest and lowest SES tertiles. To help discern the change, absolute differences between these high- and low-SES groups are also shown (Fig. 3, panel b). At the beginning of the observational period, colorectal cancer rates are stable, and a reverse gradient (higher SES, higher mortality) is evident; thus, at this early point, colorectal cancer appears to be in the natural mortality stage.

Colonoscopy was first used in 1969 and increased in uptake and diffusion thereafter (illustrated with a dashed vertical line in panel a of Fig. 3). Colorectal cancer mortality has since decreased over time, and this decrease appears to have accelerated. Following the introduction of effective screening we begin to see substantial reductions in mortality: from the peak mortality, we see a 39 % reduction in mortality by 2009. However, mortality reductions are not shared equally: far greater benefits accrued in the higher-SES group. For example, panel b shows that higher-SES areas had much higher risk in the 1960s through 1980s, as exhibited by the higher rates (panel a) and the negative absolute inequalities (panel b). Eventually (in 1996, see panel b for when the absolute differences inverted consistently), changes created a standard social gradient, with people living in higher-SES areas exhibiting lower mortality rates. Adjusted models support the graphical presentation (Table 2, Model 2). Models show that the risk of colorectal cancer mortality decreases at an accelerating rate over time and that SES and colorectal cancer mortality were inversely related in 1968. Yet, concurrent with the noted decrease in colorectal cancer mortality, results show an increase in the protective effect of SES on colorectal cancer mortality. The quadratic model shown improved in model fit over the linear model ($p < .001$).

Table 1 Race-, sex-, and age-adjusted mortality rates (per 100,000 population) by cause of death in U.S. counties, 1968–2009

Year	Multiple Sclerosis	Colorectal Cancer	Kidney Infections	Thymoma
1968	1.23	37.06	12.67	
1969	1.07	38.72	11.38	
1970	1.32	36.70	10.18	
1971	1.23	36.43	11.02	
1972	1.20	36.63	8.34	
1973	1.03	37.31	7.51	
1974	1.05	37.28	6.74	
1975	0.96	35.94	5.34	
1976	1.04	37.57	4.32	
1977	1.18	37.76	4.56	
1978	0.96	37.23	3.59	
1979	0.92	36.00	2.97	0.32
1980	0.86	36.67	2.66	0.30
1981	0.86	36.19	2.17	0.40
1982	0.95	35.81	2.22	0.22
1983	0.90	35.38	1.79	0.24
1984	0.83	36.06	2.24	0.22
1985	0.88	35.83	2.06	0.24
1986	1.21	36.79	1.89	0.28
1987	0.93	35.29	1.43	0.31
1988	0.88	35.03	1.35	0.47
1989	1.07	35.53	1.24	0.27
1990	1.01	36.31	0.94	0.22
1991	1.03	35.15	0.80	0.26
1992	1.03	34.29	0.81	0.25
1993	1.11	33.89	0.71	0.24
1994	1.00	33.09	0.61	0.17
1995	1.26	33.32	0.54	0.22
1996	1.38	33.44	0.81	0.25
1997	1.17	32.23	0.55	0.19
1998	1.22	32.58	0.67	0.21
1999	1.31	31.06	0.59	0.17
2000	1.35	30.45	0.51	0.19
2001	1.54	29.36	0.55	0.18
2002	1.51	29.55	0.44	0.16
2003	1.76	29.07	0.54	0.24
2004	1.84	26.94	0.46	0.18
2005	1.52	26.21	0.46	0.20
2006	1.44	26.29	0.36	0.22
2007	1.51	26.21	0.34	0.14

Table 1 (continued)

Year	Multiple Sclerosis	Colorectal Cancer	Kidney Infections	Thymoma
2008	1.61	25.98	0.32	0.21
2009	1.77	25.13	0.37	0.16

Figure 4 shows the mortality curves for kidney infections separated again by socioeconomic groupings. Over the observational period, we see a rapid reduction in mortality due to kidney infections. The yearly trends (Fig. 4, panel a) and differences (Fig. 4, panel b) suggest that the absolute difference in kidney infection mortality rates between high- and low-SES counties declines over time. By the 1990s, inequalities between high- and low-SES groupings are less standard and fluctuate yearly. Moreover, on the average, mortality due to kidney infections has declined and appears to be

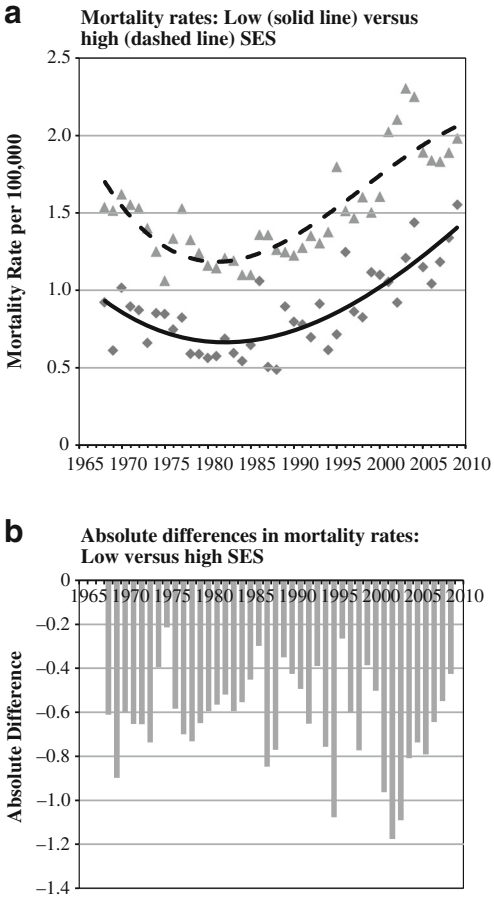

Fig. 2 Natural mortality: Mean age-, race-, sex-adjusted multiple sclerosis mortality rates among United States residents aged 25 and older (1968–2009; no prevention known)

Table 2 Mortality rate ratios (MRRs) from negative binomial regressions considering relative inequalities in cause-specific mortality rates ideally representing each stage using county-level mortality counts data from the United States (1968–2009)

	Model 1: Multiple Sclerosis		Model 2: Colorectal Cancer		Model 3: Kidney Infections		Model 4: Thymoma	
Variable	MRR	SE	MRR	SE	MRR	SE	MRR	SE
Black (ref. = white)	0.934	0.019**	1.253	0.014***	1.746	0.032***	1.366	0.042***
Male (ref. = female)	0.644	0.005***	1.367	0.003***	0.939	0.008***	1.538	0.029***
Urbanicity	0.867	0.040**	0.900	0.032**	0.895	0.043*	1.098	0.051*
Year	0.976	0.002***	0.987	0.001***			0.990	0.007
Year Squared / 100	1.001	0.000***	0.945	0.001***			1.000	0.000
Ln(Year)					0.371	0.003***		
SES	1.266	0.021***	1.076	0.012***	0.922	0.015***	0.989	0.015
SES × Year			0.992	0.000***				
SES × Year Squared / 100			0.987	0.001***				
SES × Ln(Year)					0.974	0.006***		
Pseudo-R^2	.085	***	.291	***	.292	***	.114	***
Overdispersion (α)	0.208	***	0.049	***	0.736	***	0.069	***

Notes: Results are presented in mortality rate ratios (MRR), with standard errors given in parentheses. All analyses adjust for age. Cell-years at risk = 3,149,651, except for thymoma (= 2,345,588). We thus analyzed 6.23 billion person-years for Models 1–3, and 4.97 billion person-years for Model 4. Analyses adjust for clustering and are weighted to the World Health Organization standard population.

Source: National Center for Health Statistics, 1968–2009.

*$p < .05$; **$p < .01$; ***$p < .001$

approaching a lower asymptote (ρ ~ 0.37 / 100,000). Results from Table 2 (Model 3) confirm these findings and reveal some important additions. Year covariates show the risk of mortality decreases substantially over time, with mortality rates in the late 2000s that are only 4 % to 5 % of those in 1968. However, although absolute inequalities have decreased (from 0.06 between 2006 and 2009 versus 5.17 between 1968 and 1970), relative inequalities increased log-linearly. Incorporating the SES × Year interaction improves model fit ($p < .001$). However, if we perform these same analyses accounting for birth cohort (not shown), we find no SES × Year interaction ($p = 0.439$), although SES has a larger effect throughout the period (0.867, $p < .001$).

Figure 5, panel a, shows that incidence of thymoma experienced a slight decline in mortality trends over the years. In the final period, 1996–2009, there is almost no consistent pattern of change in any of the mortality rates. The yearly level of variability is high, and there are no changes in absolute SES–related inequalities (Fig. 5, panel b). Results from Table 1 (Model 4) support these conclusions, showing no relationship between SES and thymoma during the period of observation. Further, time is not significantly related to mortality, suggesting that thymoma mortality may have reached a lower bound (ρ ~ 0.019 / 10,000).

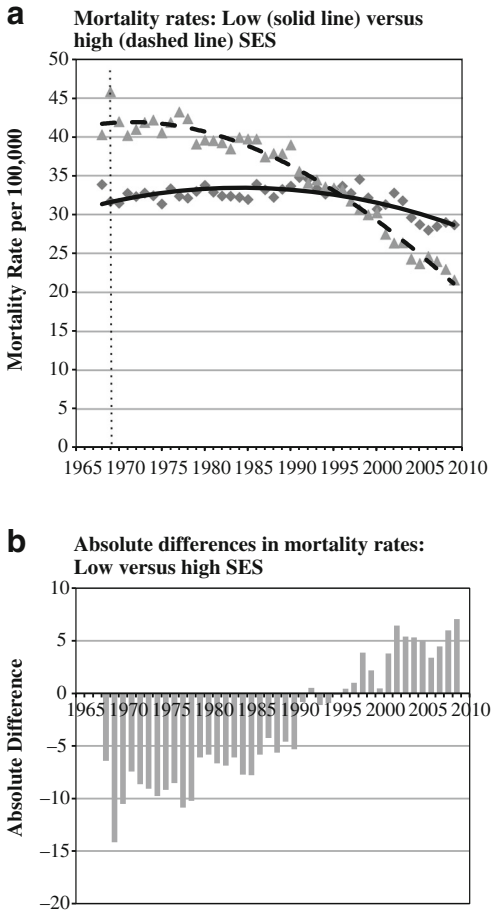

Fig. 3 Producing inequalities: Mean age-, race-, and sex-adjusted colorectal cancer mortality rates among United States residents aged 25 and older (1968–2009; t_{pk} = 1969)

Discussion

Large socioeconomic inequalities in mortality point to a powerful role for sociostructural factors in shaping health. Research on fundamental causes of disease has made progress toward explaining why new mechanisms linking SES and mortality emerge. To date, no study has examined the multiple ways that SES may be dynamically related to cause-specific mortality as human knowledge about and ability to control that disease evolves. In this study, we posit that period effects may lead to substantial increases in the influence of SES on cause-specific mortality when societies learn to control disease. In particular, we focus on how SES inequalities in cause-specific mortality may exist, may be produced in the standard direction, and then may decline and even disappear as a result of sociohistorical processes. We propose four stages in the social history of a disease: (1) natural mortality, during which inequalities in mortality are static and may even be reversed; (2) producing inequalities, in which mortality inequalities shift to favor higher status groups; (3) reducing inequalities, at

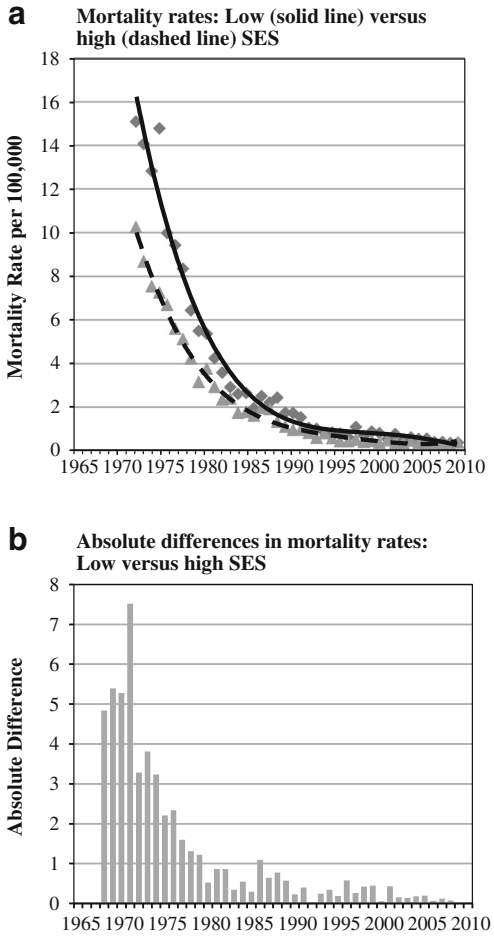

Fig. 4 Reducing inequalities: Mean age-, race-, sex-adjusted kidney infection mortality rates among United States residents aged 25 and older (1968–2009; $t_{pk} \sim 1940$)

which point mortality and, in some cases, inequalities therein are subject to compression and reduction; and (4) reduced mortality/disease elimination.

Strengths and Limitations

Our study is limited because we relied on only four, albeit informative, diseases to consider a single process. In doing so, we highlight the utility of our approach as a way to contextualize and understand future studies in hopes that it will lead to more systematic analysis. Second, although the U.S. situation provides a test case, many factors specific to the U.S. context may influence conclusions. We discuss some of these factors in international contexts, but further analysis is needed that specifically examines international contexts.

Our reliance on macro-level population data ignores micro-level dynamics, which would provide insights into micro-processes at work. In particular, the economic,

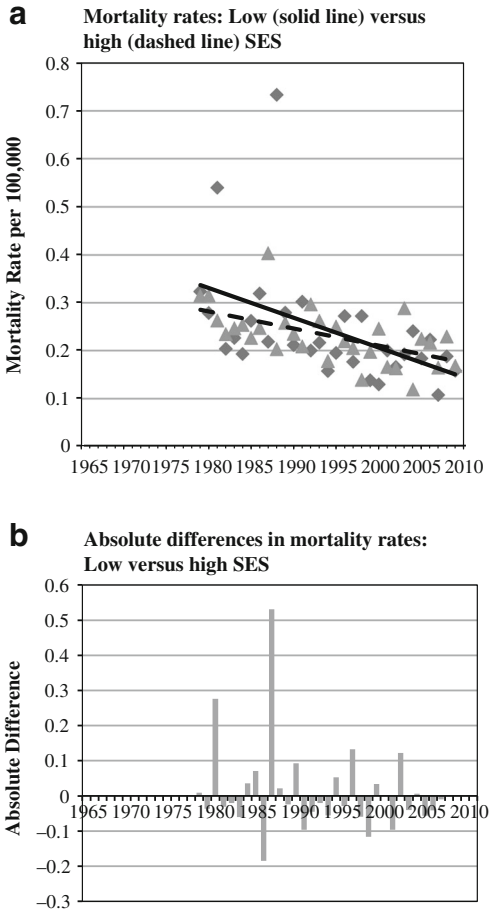

Fig. 5 Reduced mortality: Mean age-, race-, sex-adjusted thymoma mortality rates among United States residents aged 25 and older (1968–2009; t_{pk} = 1900s)

political, and social relations that determine how individuals access innovations were not considered in detail here. Moreover, data from death certificates can be biased by factors influencing diagnosis (Doria-Rose and Marcus 2009; German et al. 2011). Nevertheless, because we rely on long-term trends instead of point estimates for understanding social inequalities in disease, the potential impacts of such biases are lessened.

Data include a relatively wide period of observation from 1968 through 2009, yet the history of effective human intervention in disease predated this period, and the process was decades long. It would have been instructive to fully examine a single cause of death as it progressed through the entire process; however, the diseases studied did not allow this type of analysis, and we were unaware of a potential disease that would. Future analyses could, however, link these data to more historical information or could rely on data available from other countries over longer periods. However, FCT provides a theoretical base on which to compare different diseases at similar points in time, thereby enabling examination during an abbreviated historical period.

The strengths of this analysis outweigh these limitations. Our strategy of characterizing four ideal types of disease has allowed us to be contextually specific while highlighting different parts of a larger pattern in an instructive way. Specifically, this approach asks researchers to specify the mechanisms through which inequalities are arising in a particular disease and then further asks them to think about new ones that may be developing. Moreover, because our cases were specified *a priori* using characterizations of preventability from the data used in Phelan et al. (2004), they are likely to represent generalizable patterns of decline that should be replicable in other diseases and other places. In the following sections, we discuss how limitations can be addressed in future research.

Temporally Extending FCT

We extended FCT to understand how social inequalities in cause-specific mortality may change due to sociohistorical processes interacting with effective human intervention. In this study, we explicitly consider how inequalities are first produced and then are reduced as mechanisms influencing mortality are diffused and ultimately extinguished. Our examination of the mechanisms through which inequality are produced, reduced, and eradicated helps to explain Krieger and colleagues' (2012) findings that inequalities seem to be simultaneously rising, falling, and remaining stable. Social inequalities in cause-specific mortality rise partly because increasing capacity to affect mortality is unevenly distributed. Thus, social inequalities may reverse when they start inverted (with higher risk in higher-SES groups), as was the case for colorectal cancer discussed earlier. However, after being produced, inequalities may remain for substantial periods before being reduced, and they may reduce in absolute but not relative terms even while the population mortality rate declines.

Stages of Social Inequalities in Cause-Specific Mortality

We proposed that the social history of disease transitions through four stages: (1) natural mortality; (2) producing inequality; (3) reducing inequality; and (4) reduced mortality/disease elimination. We used four causes of death to elucidate these stages. However, stages represent a generalization of what is likely to be a complex process. Social inequalities in cause-specific mortality might plausibly fluctuate through producing and reducing inequalities and even reduced mortality stages as knowledge about the risk of cause-specific mortality and interventions to effectively reduce it evolve and become more or less efficient. Research by Edwards et al. (2010) suggested that screening innovations caused substantial reductions in colorectal cancer mortality, while changes in health behaviors helped to reduce the risk of colorectal cancer further. In contrast, mortality from tuberculosis (TB) has been controlled for a long time. However, as TB has evolved, treatments have become less effective, and social inequalities in death are again rising among those who live in crowded conditions or who are (or have friends and family members who are) exposed to (multi-) drug-resistant forms of TB (Farmer 2003). Finally, multiple processes may cause overlapping stages rather than a singular event leading to multiple, overlapping stages. Thus, although we have clarified a complex process, we believe that analysis should consider the range of sociohistorical processes that might characterize how society shapes disease.

Factors Influencing Progression Through the Stages

One conclusion of this study is that the greater the rapidity of proliferation of prevention and treatment, the less time each stage may take, and the more rapid inequalities can be controlled. As such, the following describes some factors that may influence the progression through each stage.

The type of medical innovation may help shape the size and form of inequality in mortality. One example of how different types of innovation give rise to different social inequalities can be derived from contrasting prevention innovations for polio and lung cancer in the United States. Polio is an acute viral disease that causes death (with a case fatality rate = 5 % to 10 %) only when polio-induced paralysis affects the respiratory system and results in suffocation (Trevelyan et al. 2005). Although highly infectious, polio was nearly eliminated in just three years after the introduction and rapid widespread use of inactivated poliovirus vaccine (IPV) in 1955. This innovation was rapidly extended to the entire population irrespective of SES and resulted in disease elimination in 1962.

In contrast, although the discovery that smoking could cause lung cancer occurred in the same historical period (Doll and Hill 1956), behavioral change is harder to achieve, carries far higher personal cost, is subject to substantial social forces influencing the uptake and maintenance of behaviors over the life course, and diffuses more slowly than did the polio vaccine. Thus, more than 40 years later, lung cancer remains in the increasing inequalities stage (Honjo et al. 2006; Rubin, et al. 2014; Singh et al. 2002), and rising smoking rates among women is a prime reason for a narrowing gender-mortality gap (Preston and Wang 2006).

Duration of time inhabiting the increasing inequalities stage may be prolonged further if processes of inequality are multiplied or compound. In a thorough ethnographic study, Lutfey and Freese (2005) showed that with regard to diabetes, nearly every level of analysis plays host to a process of inequality. They highlighted differences in types of care, educational resources, and capacity of patients to understand and adhere to treatment regimens. In trying to intervene on diabetes, research has suggested that achieving behavioral change at the individual level can be difficult, and effective interventions incorporate both individual and contextual changes (de Silva-Sanigorski et al. 2010; Economos et al. 2007). The number of inequalities at every level of consideration may magnify social inequalities by delaying transmission of effective prevention to those with lower SES. If multiplied, processes of inequality may become much more impactful and are likely to delay or prevent the process of inequality reduction.

The entire process may similarly be prolonged when disease outcomes and preventions are due to exposures over a life course (Dannefer 2003; Kuh and Ben Shlomo 2004). For example, smoking takes approximately 20 years of poor health behaviors to cause lung cancer (Alberg and Samet 2003). Similarly, stomach cancer, generally a cause of death among older individuals, has been related to *Helicobacter pylori* infections in childhood (Forman et al. 1991; Huang et al. 1998). Colorectal cancer is related to long-term impacts of lifestyle factors, including obesity, physical inactivity, and increased ingestion of processed meat (Edwards et al. 2010). Similarly, inequalities may further be delayed if treatments are developed using people from advantaged

backgrounds, resulting in medical treatments that are targeted toward treating those from similarly advantaged populations (Ge et al. 2009).

Finally, cultural factors not necessarily related to SES may modify the uptake of a particular medical innovation. For instance, recent evidence has supported public health efforts for universal adoption of the human papilloma virus (HPV) vaccine (Colgrove 2006). However, a nexus of inequalities surround the distribution of the vaccine, including some parents who do not know about the benefits of vaccination or elect not to vaccinate their children against HPV (Polonijo and Carpiano 2013). Furthermore, cultural factors influencing the wholesale uptake of such preventive technologies, or especially of new information regarding effective health-enhancing lifestyle choices, may modify both the original risk of death as well as the rapidity with which cultures transition through each stage (Cockerham 2005).

Broad Implications

Our approach relies on the framing of DTT (Chesnais 1986/1992) and extends it to interrogate the role of social inequalities in understanding variation in the decline in mortality rates. Specifically, although DTT notes that control of mortality is associated with changes in fertility, this study further suggests that control of mortality is also associated with increasing disparities in mortality. The results from this study might then suggest that one factor linking SES to differences in fertility (Becker 1960) may be differences in mortality arising within subsets of the population and in different contexts of disease.

Caldwell (2001:25) stated that "demographic and social theory attributes a good deal [of decline in mortality] to economic and social change." Arguments relating to cohort bias emerging from examinations of improvements in nutrition are often used to help explain social inequalities in health and mortality (Fogel 1994; McKeown 1976). A clear problem here is that the attribution of both social inequalities and declines in mortality could be due to cohort-based differences in access to food availability; we found that such an explanation might be in operation for kidney infections but not for colorectal cancer (results not shown). A number of theorists have posited that cohort effects might reflect how health knowledge is passed down to children. For example, Masters et al. (2012) posited that educational inequalities arise partly because of reductions in incidence given that children are actively taught appropriate health information to make health-beneficial choices. Furthermore, Cockerham (2005) suggested that health lifestyles are shaped by status groups who are not accidental in their lifestyle attitudes but are instead actively managing them to effectively avoid disease based on current health information. Health lifestyles may integrate both structural and individual choices. Speaking to individual-level decisions, it may be useful to note that as health is increasingly influenced by preventive efforts earlier in life, individuals' efforts to extend life—partly through avoidance of risky but enjoyable or attractive activities, such as smoking (Carbone et al. 2005)—may depend somewhat on the perceived value of adding years at the end of life. Nevertheless, structural factors may help to support healthy lifestyles because educational institutions provide a structure on which health lifestyle decisions are made, influencing (for example) participation in regular physical

activity and nonsmoking (Clouston et al. 2015). Colorectal cancer incidence and mortality are being simultaneously reduced as individuals improve health behaviors while increasing regular use of preventive medicine to prevent and treat malignancies (Edwards et al. 2014). Cohort-based reductions in inequalities are an integral part of the inequalities process as people first create and use, and then pass on to children, the practicalities of extending healthy life.

Diffusion of Innovation

Diffusion of innovation was viewed as a mechanism for the creation of social inequalities in mortality. A broad theory further develops this association outside the sociology and demographic literatures. For example, researchers have found a consistent and broad-based knowledge gap between lower- and higher-SES areas (Hwang and Jeong 2009). In political science, this is one reason given for increasingly polarized political debates in Spain and in the United States (Fraile 2011; Hindman and Yan 2015), where clustering of knowledge and information is believed to have led to fundamentally different beliefs and levels of knowledge about politicized debates. This has been further formalized in the economics literature as an S curve that highlights the potential utility of modeling change using a differential equations modeling approach while suggesting that social inequalities tend to develop in the diffusion of new technologies as those with more social power access those technologies first (Kuandykov and Sokolov 2010). Diffusion is thus seen as proliferating through social networks between individuals, with higher connectivity resulting in more rapid and efficient diffusion of innovations (López-Pintado 2008). If so, then high levels of income inequality or residential segregation in interpersonal communication networks may further delay the distribution of effective preventive technologies, potentially helping to explain the persistent effect of the influence of contextual inequalities on health (Pickett and Wilkinson 2015; White et al. 2012). Our study thus broadens that literature, suggesting that medical and public health innovations are also subject to inefficiencies in diffusion, and further notes that such inefficiencies in diffusion of medical technologies may result in substantial and long-term inequalities in the risk of mortality.

International Research

FCT is generally applicable to countries outside the United States, in terms of both within-country inequalities and global between-country differences. Significant global inequalities could result if some countries are more capable of making effective universal efforts, as is the case in the United Kingdom, where school girls are vaccinated against HPV as part of the National Health Service immunization program (NHS 2012). Because of data limitations and in the interest of contextual clarity, we focused on U.S. data. However, taking inspiration from an excellent study of diffusion in water hygiene that documented the receding influence of cholera in Europe after the 1860s (Briggs 1961), we also note that our model is generalizable to comparisons made both within and between other countries. For example, differences may emerge between nations if entire nations have difficulty distributing preventions. For example, the

United States is lagging in life expectancy in part because of its inability to effectively intervene at a population level on important dimensions of inequality, including health behaviors (Ho and Preston 2010).

Future Directions

This approach suggests multiple areas of research that social scientists could develop further. First, identifying historical points of change in our knowledge and technology relating to a disease will help us to understand and characterize both the impact of types of disease prevention and the stages that each disease currently inhabits. Moreover, incorporating indicators of the prevention under study would help researchers examine specific mechanisms relative to each cause of death. Second, considering how type of prevention (e.g., medical, pharmacological, surgical, behavioral), disease etiology, and exposure (e.g., environmental, behavioral, occupational) function within a social, economic, and political structure can help to determine the time spent in each stage and the degree to which social inequality affects disease outcomes. Third, examining variation in underlying patterns of decline could help us to better understand diffusion and model variability in t_{pk}. Finally, using cross-national approaches to compare the role of social policy in preventing death both within and between countries may prove to be a useful way of considering the importance of social context and especially of social policy in modifying the timely and equitable distribution of new medical treatments.

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